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G1A
G1U
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(54) Method and apparatus for spectral measurement

(57) A technique for the measurement of the spectral lineshape (amplitude and frequency stability) of an electromagnetic radiation source eg. a semiconductor laser (1) involves the comparison of an input signal (A) and a reference signal (B) which are frequency offset by a pre-determined amount (Δf). Signals output from a comparator stage (5) are integrated for a given interval of time and sampled to provide a set of correlation coefficients. As described the comparator (5) comprises a 4×4 multiport fibre-coupler junction (Fig. 2 not shown), producing complex amplitude products of the two signals, with quadrature phase. Frequency offset device (7) uses a coiled optic fibre bonded about a piezoelectric crystal driven by a sinusoidal voltage. Frequency offset selection and integration timing may be controlled by microprocessor or computer. The method above may be used to study semiconductor lasers (1) in terms of noise processes. Of particular interest is the correlation between amplitude and phase noise.

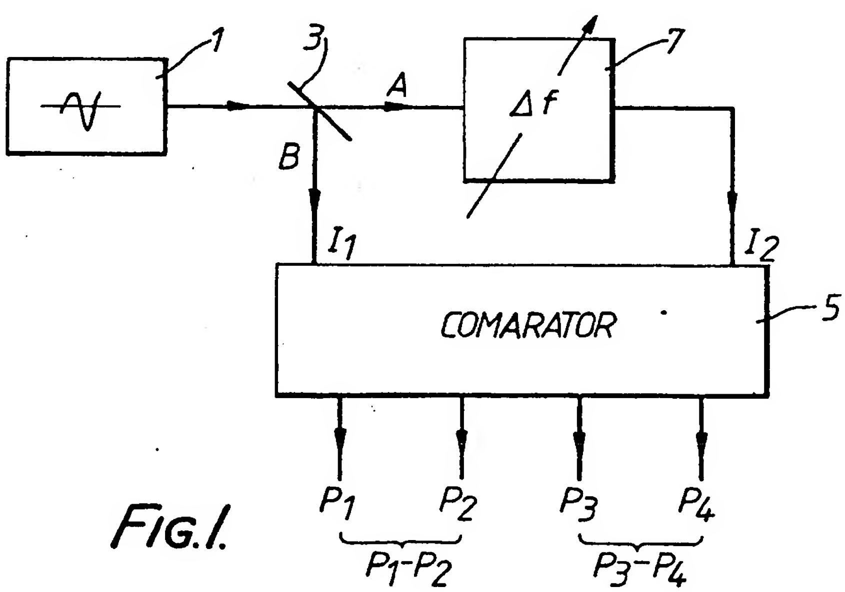

FIG.1.

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The drawing(s) originally filed was/were informal and the print here reproduced is taken from a later filed formal copy.

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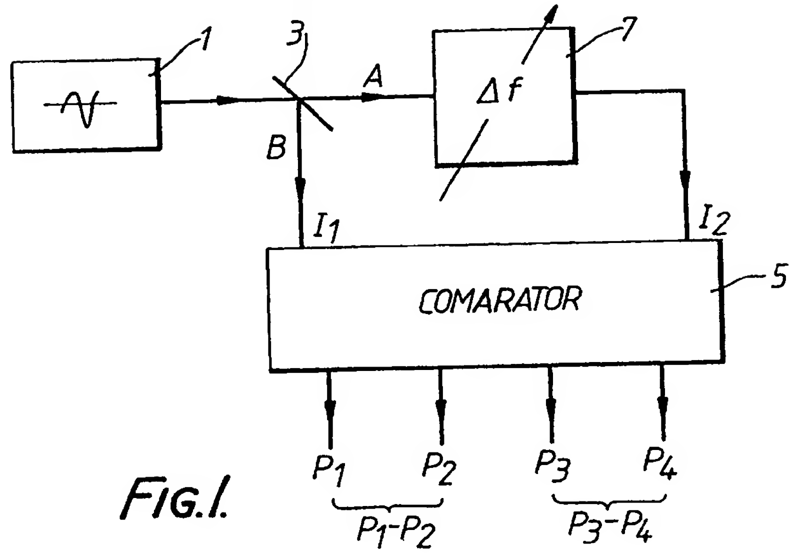

FIG.1.

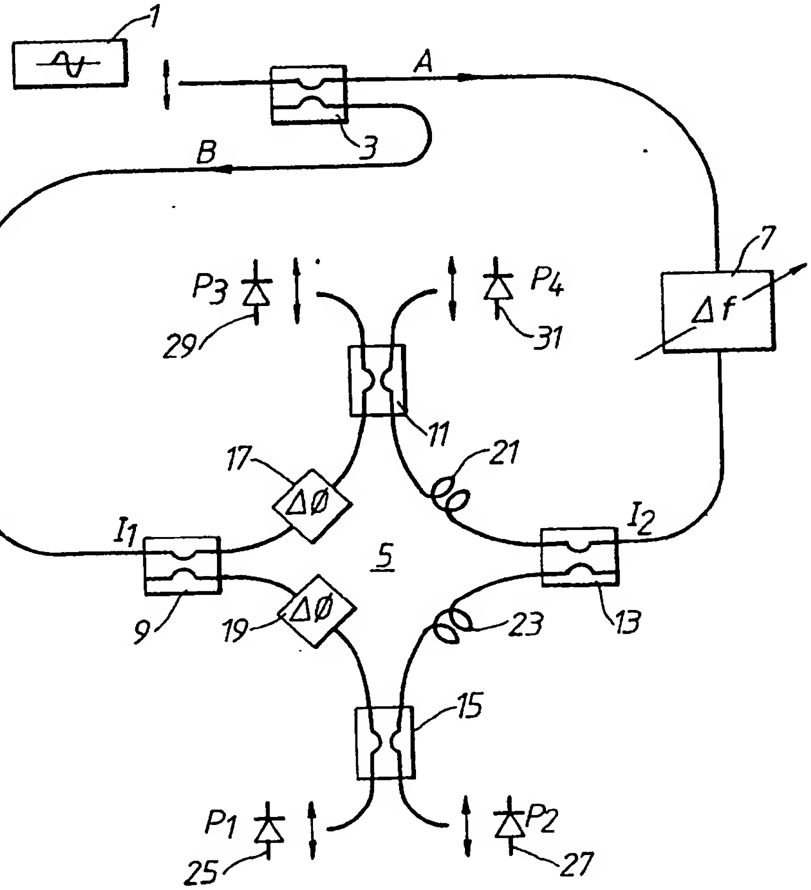

FIG.2.

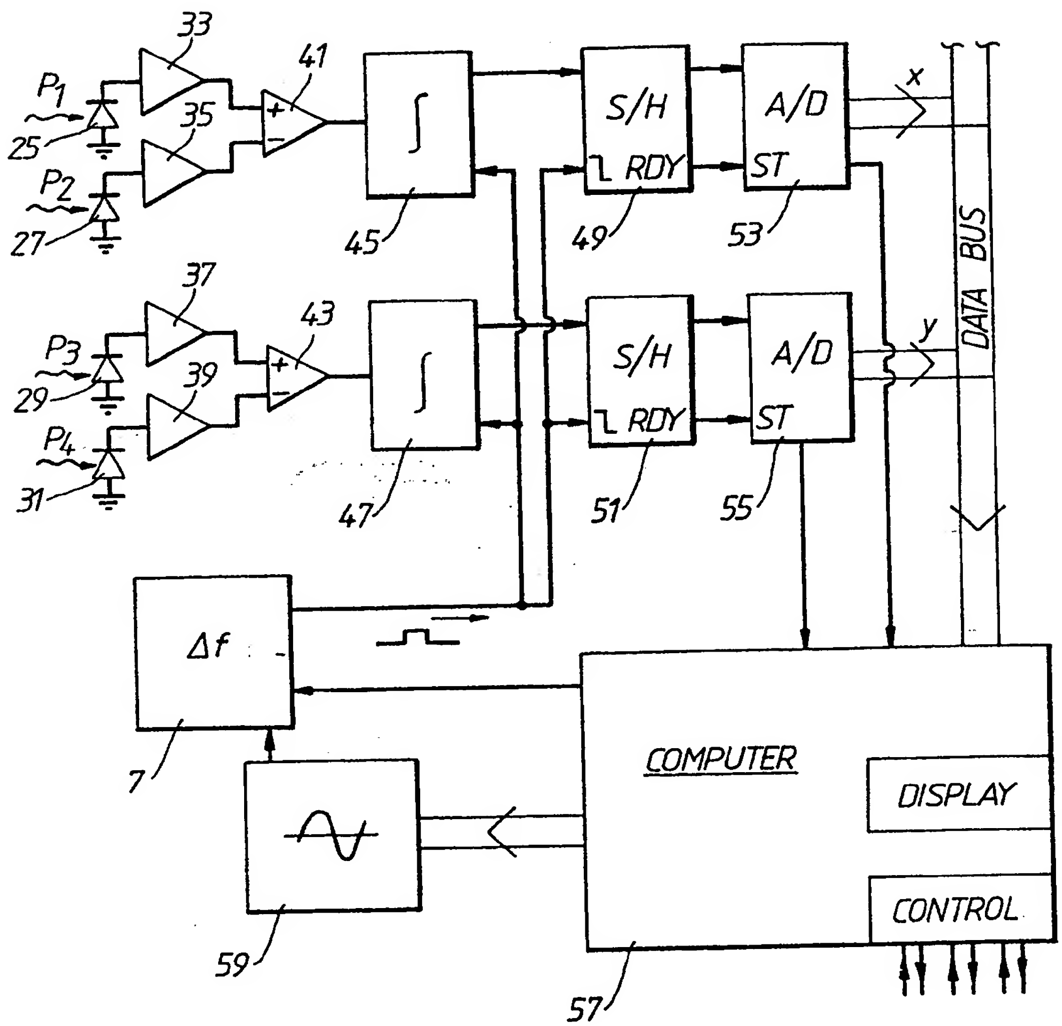
33
41
P1
35
25
P2
27
45
S/H
RDY
49
A/D
ST
53
x
DATA BUS
37
43
P3
39
29
P4
31
47
S/H
RDY
51
A/D
ST
55
y
Δf
7
59
COMPUTER
DISPLAY
CONTROL
57

FIG.3.

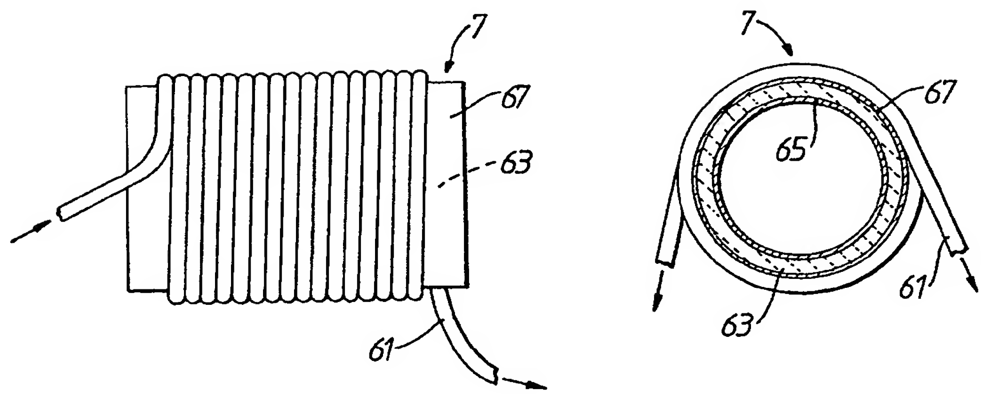

FIG. 4.

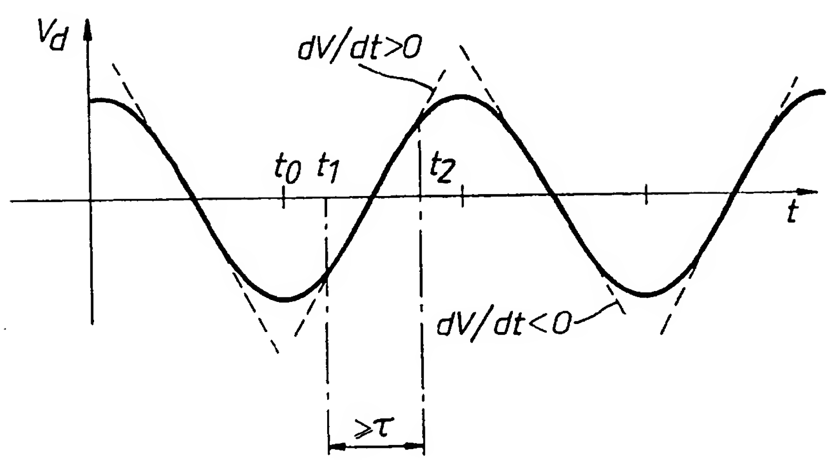

FIG. 5.

SPECIFICATION

Method & apparatus for spectral measurement

TECHNICAL FIELD

The present invention concerns a method and apparatus for spectral measurement, and, in particular, a technique for measuring the complex correlation coefficients for an electromagnetic radiation signal.

Spectral lineshape and linewidth measurements of semiconductor lasers are important for determining the viability of such sources for coherent applications. The spectral lineshape also provides information about the noise processes within the laser itself. Both amplitude and frequency stability are of interest.

BACKGROUND ART

Existing measurement techniques are of limited frequency resolution.

Hitherto, linewidths of coherent sources have been measured using commercially available spectrum analysers. For optical sources it has been usual to split the optical signal into two parts. One part is delayed with respect to the other by a sufficient amount so that there is no mutual coherence between the two signals. On homodyning these two signals, the difference frequency is nominally zero and this is spectrally analysed. The measured linewidth of this baseband signal is then twice that of the source. Only the spectral amplitude is measured and phase information is not given by this measurement.

It is known to use a 4×4 multiport junction to generate correlation coefficients and by way of background the interested reader is referred to the following article by N.G.Walker et al, entitled "Simultaneous Phase & Amplitude Measurements on optical signals using a multiport junction", Electronic Letters Vol 20 No 23 pages 981–983 (Nov 1984).

DISCLOSURE OF THE INVENTION

The invention considered herein is intended to provide a method and apparatus for spectral measurement, the same being capable of affording improved frequency resolution.

According to the invention thus there is provided a method for spectral measurement, a method of the type wherein an input signal and a reference signal are compared and quadrate complex amplitude product terms derived therefrom, characterised in that said signals are offset in frequency by a variable frequency shift; and, each said term is integrated for a suitable period of time and sampled, samples being taken for different values of the frequency shift by which said signals are offset.

In the method aforesaid the input signal and the reference signal may be derived from different sources. In this case the samples taken correspond to complex cross-correlation coefficients for each value of frequency shift. Alternatively, the input signal and the reference signal may be derived from a common source, the samples then corresponding to the complex auto-correlation coefficients of that source.

In order to obtain satisfactory averaging, the period of integration is chosen to correspond to many periods of the frequency shift. The term "suitable period" as used hereinbefore, shall be construed accordingly.

Apparatus for performing the method aforesaid may comprise:–

amplitude and phase comparator means, this having first and second input ports and being responsive then to input signal and reference signal respectively, this means providing quadrature complex amplitude product terms as output in response to said signals;

frequency shift means inserted at one of said input ports, to apply each of a set of different frequency offsets; and,

integration and sampling means, co-operative with said amplitude and phase comparator means, reponsive thus to said product terms.

The amplitude and phase comparator means may comprise, for example a 4×4 multiport junction formed of a network of beam splitters or power dividers. For application to signals at optical frequency, the power dividers may each consist of a fibre coupler. In the latter case, the optical outputs from the 4×4 junction may be detected by diodes and the diode currents combined in subtractive pairs to provide the requisite product terms aforesaid.

For optical application, the frequency-shift means may have the form of a coiled optical fibre bonded about the periphery of a piezoelectric crystal former which latter is driven by a periodic voltage drive signal. For convenience, the drive signal provided may be of sinusoid waveform.

The integration timing and frequency shift adjustment may be controlled by suitable electronic and/or computer means—eg. by a microprocessor. Measured data may be stored in and processed by the same electronic and/or computer means or, in preference to this, by another dedicated computer or processor.

BRIEF INTRODUCTION OF THE DRAWINGS

In the drawings accompanying this specification:–

Figure 1 is a block schematic diagram showing apparatus provided in accord with this invention.

Figure 2 is a block schematic diagram showing the optical part of the apparatus including a 4×4 multiport junction comprised of fibre couplers;

Figure 3 is a block diagram of the electrical processing part of apparatus and which may be used in conjunction with the optical apparatus shown in the preceding figure;

Figure 4 shows, in side and front elevation, a frequency–shift device for optical application and for use in the apparatus of Fig. 2 preceding;

Figure 5 illustrates the waveform of a drive signal, a signal that may be used to operate the device of the preceding figures.

DESCRIPTION OF A PREFERRED EMBODIMENT

So that this invention may be better understood, an embodiment thereof will now be described and reference will be made to the accompanying drawings. The description that follows is given by way of example only.

The technique that is considered here is general and is applicable to any frequency. For the purpose of description, however, consideration will now be restricted to optical application and in particular to an embodiment suited to signals at eg. 1.55 microns wavelength and thereabouts. With a single source, spectral auto-correlation function information about noise in semiconductor lasers can be obtained, and it is this measurement that will be considered below. Alternative to this, different sources can be applied to the comparator inputs and cross-correlation measurement obtained.

As shown in Fig. 1 the signal from a laser source 1 is divided by means of a beam splitter (or power divider) 3 to provide an input signal A and a reference signal B. One of these signals, the reference signal B, is applied directly to a first input port I, of an amplitude and phase comparator 5. The other signal, the measured input signal A, is applied to a second input port I, via a frequency-shift device 7, which device serves to offset the frequency $f(=\omega/2\pi)$ of the input signal and by a prescribed and variable amount $f(=\Omega/s\pi)$. The comparator 5 serves to provide complex amplitude product terms differing by quadrature phase and to this end provides at its output ports signals P_1, to P_4, which are phase diverse and comprised of the mixed input signals A,B.

A practical arrangement for the optical part of the comparator 5, a 4×4 multiport fibre-coupler junction, is shown in Fig. 2. This junction comprises a network of four 3dB fused fibre couplers 9,11,13 and 15, all arranged symmetrically. In two of the branches of this network, phase-shift components 17 and 19 are inserted. These latter components 17 and 19 are adjusted to produce the requisite phase diversity. Polarisation controllers 21 and 23 are inserted in the remaining two branches of the network and are adjusted for optimum polarisation alignment.

The four optical output signals P_1, to P_4, provided by the multiport junction, are directed onto a set of corresponding photodiodes 25, 27, 29, and 31 and detected. The diode currents, after individual pre-amplification by amplifiers 33, 35, 37, and 39, are then referred in pairs (P_1, P_2) and (P_3, P_4) to differential amplifiers 41, and 43. The resulting currents correspond to differences of power measurements as given below:–

$$P_1-P_2=2A(t)B(t)\cos(\Omega t-\phi);$$

$$P_3-P_4=2A(t)B(t)\sin(\Omega t-0);$$

where: $P_.$, to P_4, are the power measurements obtained, A(t) and B(t) are the amplitudes of the input and reference signals respectively, Ω is the inserted angular frequency offset, and, ϕ, is an arbitrary phase dependent upon the optical path lengths through the network. It will be noted that these two terms correspond to the complex amplitude products of the input and reference signals and differ by quadrature phase.

In the remaining electrical processing part of the apparatus, as shown in Fig. 3, these latter signal terms are integrated and sampled to provide a set of data $(\bar{x},\bar{y})$:–

$$\bar{x}=\int.(P_1-P_2)dt \quad ;$$

$$\bar{y}=\int.(P_3-P_4)dt$$

It can be shown that the complex term Z defined by:–

$$Z=x+jy \quad :(x=\int_{-\infty}^{+\infty}(P_1-P_2)dt;$$

$$y=\int_{-\infty}^{+\infty}(P_3-P_4)dt)$$

is equivalent to:–

$$Z(\Omega)=\exp(j\phi)\int_{-\infty}^{+\infty}A(\omega-\Omega)\,B^*(\omega)\,d\omega/\pi$$

For $\tau\gg 2\pi/\Omega$ $\bar{x}\rightarrow x$ and $\bar{y}\rightarrow y$

The time averaged signal outputs $(\bar{x},\bar{y})$ thus provide a measure of the correlation coefficients $Z(\Omega)$. For practical measurement, the time average is taken over a finite interval τ, an interval that is long compared with the period of the frequency shift (ie.$\gg 2\pi/\Omega$). The integration then approximates infinite limits, and is consistent with the theory.

The quadrature terms thus each pass through an integrator 45, 47 and are sampled after the period of integration τ by respective sample-and-hold units 49 and 51. The samples are then digitised by respective analogue-to-digital convertors 53 and 55 and the data $\bar{x},\bar{y}$ stored in the memory of a computer 57 for subsequent data processing.

The computer 57, acts as both a controller and a data-logger. The computer 57 controls the frequency of a signal generator 59, which in turn controls the frequency offset Ω inserted by the optical frequency shift unit 7. Whilst the frequency shift has a fixed value for the integration timeτ, the frequency shift is valid at a valueΩ. A pulse, the "valid" pulse, is then sent to the integrators 45, 57 and the sample-and-hold circuits 53, 55. The integrators, 45, 47 detect the rising edge of this pulse and are reset. Whilst the freqency shift Ω is valid, the power differences of the multiports (ie the quadrature terms) are integrated. When the frequency shift Ω becomes invalid, ie. at the falling edge of the pulse, the sample and hold circuits 49, 51 sample the outputs of the integrators 45, 47 and analogue to digital conversion commences. When the digital data x,y is ready, the computer 57 is interrupted and the data is logged.

When the computer 57 has sufficient data $(x_1, y_1, (\bar{x}_2, \bar{y}_2); \ldots (\bar{x}_n, \bar{y}_n)$ at that particular frequency shift Ω, it increases the frequency of the signal generator 59, thus increasing the optical frequency shift, and the procedure above can be repeated.

Provision is made to allow for different integration times appropriate to different frequency shifts. Roughly speaking the integration time must be many periods of the frequency shift in order to obtain satisfactory averaging and rejection of unwanted frequency components so that the integration approximates to one over infinite limits.

With just the one computer 57, the control of the procedure will either be done as interrupts to the processing program, or control and data-logging will preceed the processing. Therefore, two computers or microprocessors would be preferable, one dedicated to control, the other dedicated to data processing.

Choice of frequency shift unit 7 is not critical. Any unit capable of providing a constant frequency shift over the requisite range of integration time values and over the range of shifts derived then would suffice.

The frequency shifter 7 shown in Fig. 4 is based upon change of signal phase, which change is proportional to time over a period of time τ. The shifter 7 comprises a length of optical fibre 61 which has been wound around and bonded to the periphery of a piezoelectric crystal 63 which, in the embodiment shown, is tubular in shape. Electrodes 65, 67 are provided on the inside and outside surfaces of the tubular crystal 63 and a periodic drive voltage applied. The crystal 63 will thus expand and contract periodically, and will vary the length of the fibre 61. The optical path length and thus signal phase will be varied periodically accordingly. For practical purposes it is sufficient to apply a sinusoid waveform voltage drive signal (Fig. 5). As can be seen from the graphical representation, the voltage change with time, dV/dt, approximates a linear change between limits, eg. t_1. t_2. and therefore will provide a linear phase change over the period $t_2,-t_1$, $(\geqslant\tau)$. These limits t_1, t_2, will differ according to drive signal frequency and or amplitude. The rising or fall slopes can be used to provide positive and negative frequency shift, respectively. The frequency shift Ω can thus be changed by changing eg. the frequency of the drive signal. Corresponding changes in integration timing would then be effected by the computer or microprocessor 57.

CLAIMS

What we claim is:–

1. A method for spectral measurement, a method of the type wherein an input signal and a reference signal are compared and quadrature complex amplitude product terms derived therefrom, characterised in that said signals are offset in frequency by a variable frequency shift; and, each said term is integrated for a suitable period of time and sampled, samples being taken for different values of the frequency shift by which said signals are offset.

2. Apparatus for performing the method of claim 1, this apparatus comprising:–
amplitude and phase comparator means (5), this having first and second input ports (I_1, I_2,) and being responsive thus to input signal (A) and reference signal (B) respectively, this means (5) providing quadrature complex amplitude product terms as output in responsive to said signals (A,B);
frequency shift means (7) inserted at one of said input ports(I_2,) to apply each of a set of different frequency offsets; and,
integration and sampling means (49, 51, 53 and 55), co-operative with said amplitude and phase comparator means (5), responsive thus to said product terms.

3. Apparatus, as claimed in claim 2, wherein the amplitude and phase comparator means (5) comprises a 4×4 multiport optical fibre coupler junction (9, 11, 13, and 15);
a set of four photodiodes (25, 27, 29 and 31) ie each responsive to a respective output port of the junction; and,
a pair of differential amplifiers (41 and 43) connected to the photodiodes in pairwise manner (25 and 27, 29 and 31).

4. Apparatus, as claimed in either claims 2 or 3, wherein the frequency shift means (7) is a device of the type capable of inserting a change of phase and wherein this phase change is variable in linear proportion to time.

5. Apparatus, as claimed in claim 4, wherein the frequency shift means (7) comprises a length of optical fibre (61); and,
phase control means (63) co-operative with said fibre (61) to change the length thereof periodically.

6. Apparatus, as claimed in claim 5 wheren the phase control means (63) comprises:–
a piezoelectric crystal former (63); and,
a voltage generator (59), this being connected to electrodes (65, 67) adjacent to the former (63) to apply a periodic voltage thereto.

7. Apparatus, as claimed in claim 6, wherein the voltage generator (59) is adapted to provide a drive voltage of sinusoid waveform.

8. Apparatus, as claimed in any one of preceding claims 2 to 7, wherein the value of each frequency offset, provided by said frequency shift means (7), is controlled by computer control means (57).

9. Apparatus, as claimed in claim 6, wherein the frequency of the periodic voltage is controlled by computer control means (57).

10. Apparatus, as claimed in any one of preceding claims 2 to 9, wherein timing control for said integration and sampling means (49, 51, 53 and 55) is provided by computer control means (57).

11. Apparatus for performing the method of claim 1, this apparatus being constructed, adapted and arranged to perform substantially as described hereinbefore with reference to and as shown in the accompanying drawings.

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